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ORIGINAL PAPER

Effect of Selected Pretreatments on Impregnation of Curcuminoids and Their Influence on Physico-chemical Properties of Raw Banana Slices

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Abstract The effect of pretreatments, namely, blanching, ultrasound, vacuum and their combinations on curcuminoid impregnation in raw banana slices, was studied in conjunction with treatments in pure water as well as in 10 % NaCl solution. The treatments such as ultrasound, vacuum and combination of vacuum and blanching with ultrasound resulted in higher curcuminoid infusion compared to control for both pure water and 10 % NaCl osmotic treatments. The blanching treatment resulted in lower infusion of curcuminoids as compared to that of control due to the gelatinisation of starch present in banana. Further, the increase in surrounding solution concentration from pure water to 10 % NaCl resulted in enhanced curcuminoid infusion (e.g. from 85 to 95 mg/100 g for combined vacuum and sonication treatment). However, the direction of the mass transfer of water as well as solid was reversed. The samples subjected to combined vacuum and sonication treatment resulted in lowest compressive force, highest infusion of curcuminoids and highest total colour difference compared to other treatments. Besides, the dehydration of such product also resulted in the highest retention of curcuminoids compared to the individual treatments. The present study concluded that osmotic treatment can be a feasible technology for the infusion of functional ingredients into foods without altering its matrix. The extent of infusion can be significantly enhanced by the application of combined treatment such as vacuum and ultrasound.

Keywords Osmotic dehydration · Raw banana · Curcuminoids · Ultrasound · Vacuum · Blanching

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Introduction

The development and consumption of functional foods, or foods that promote health not merely basic nutrition, is on the rise. In recent years, interest has grown in developing new functional foods that have health-promoting and/or disease-preventing properties beyond the basic function of supplying nutrients (Rozek et al. 2009). The estimated global market of functional food industry is expected to be 176.7 billion USD with a compound annual growth rate of 7.4 % (Roberts 2009). The range of functional foods that have potential health benefits has grown tremendously. It includes baby foods, bakery goods and cereals, confectionery, dairy foods, ready meals, snacks, soft drinks such as energy and sport drinks, meat products and spreads. These functional foods are associated with various types of benefit and involve vitamin and mineral fortification, cholesterol reduction, antioxidants, phytochemicals, dietary fibre, herbs and botanicals, probiotics, prebiotics and symbiotics (Alzamora et al. 2005).

However, osmotic treatment is widely used to modify the composition of solid foods (e.g. fruits, vegetables, meat and fish) by partially removing water and adding solutes (Rozek et al. 2010a; Ferrari et al. 2013). During osmotic dehydration, the biologically active compounds are transferred from surrounding solution to the food by a process of diffusion in which a naturally occurring cell membrane functions as a semi-permeable membrane. The intercellular spaces present in the natural food matrix decide the extent of infusion of biologically active compounds. The kinetics of infusion, viability of infusate, interaction between the food components, cellular structure and mechanical properties are the few major concerns regarding the infusion of biologically active compounds in solid foods (Bellary et al. 2011; Bellary and Rastogi 2012). A number of techniques have been proposed to enhance the inherently low rate of osmotically induced mass transfer, including partial vacuum (Rastogi and Raghavarao

1996; Fito et al. 2001; Derossi et al. 2013a, b), high pressure (Rastogi et al. 2007) or ultrasound (Rastogi 2011). Pretreatments such as freezing, high-pressure, high-intensity electric field pulses have been reported to enhance mass transfers during osmotic treatments (Tedjo et al. 2002; Ade-Omowaye et al. 2000; Amami et al. 2006; Mayor et al. 2006).

Use of natural food colourants in impregnation is expected to have dual value by providing exotic colour and enhancing nutritional status of foods, besides being more appealing and rewarding. Turmeric (*Curcuma longa* L.) is one of the spices, which is a rich source of antioxidant, namely, curcuminoids with the principle ingredient being curcumin and other two analogues such as demethoxycurcumin and bisdemethoxycurcumin (Govindarajan 1980). Curcuminoids were demonstrated to possess anti-inflammatory, antimicrobial, antioxidant, antiparasitic, antimutagenic and anticancer activity (Joe et al. 2004; Goel et al. 2008). Recently, Bellary et al. (2011) explored osmotic treatment as a method to infuse curcuminoids in coconut slices. The highest incorporation of curcuminoids could be achieved when the concentration of osmotic solution was minimum (i.e. 0 % or pure water). Further, Bellary and Rastogi (2012) studied the impregnation of curcuminoids into coconut slices using the surrounding hypotonic or hypertonic solutions.

The present work deals with the development of dehydrated raw banana slices infused with curcuminoids. The objectives of the present work were to study the effect of selected pretreatments (blanching, ultrasound and vacuum) and their combinations on curcuminoid infusion in conjunction with pure water (0 %) or osmotic treatment (10 % NaCl) as surrounding solution concentration. The effects of pretreatments on physico-chemical as well as structural changes were also examined.

Materials and Methods

Materials

Raw bananas (*Musa Cavendish*) were purchased from a local market and were manually peeled, cut into slices (30 mm in diameter, 2 mm in thickness) and further divided into four sections. Curcumin powder and NaCl were procured from M/s. Sigma-Aldrich and Merck, India, respectively. The curcuminoids in the standard curcumin powder sample were found to be curcumin (major fraction), demethoxycurcumin and bisdemethoxycurcumin (Naidu et al. 2009; Bellary et al. 2011).

Impregnation Treatments

The banana slices, thus obtained, were subjected to various pretreatments such as blanching, ultrasound and vacuum as well as their combinations in conjunction with treatments in pure water or 10 % NaCl for 5 h containing water-soluble curcuminoids (0.5 g/100 mL) (Sowbhagya et al. 2005). The mass ratio of sample to impregnating solution was maintained at 1:5. The samples were withdrawn at regular intervals, rinsed quickly and blotted gently with tissue paper and then weighed. The moisture content of the samples was determined by drying samples in a vacuum oven at 60 °C for about 24 h (AOAC 1998, procedure number 934.06). Raw banana slices immersed in pure water (0 %) and 10 % NaCl without any pretreatment were referred as respective controls.

Blanching Treatment

The samples were subjected to the blanching treatment by immersing them into a beaker containing hot water (70–90 °C) up to 2 min. The temperature of the blanching solution was maintained using thermostatically controlled water bath (Model MA 184; M/s Marconi, Brazil). After the blanching treatment, the samples were subjected to tap water to cool the samples. Further, the samples were blotted gently with tissue paper, weighed and then subjected to impregnation treatment. Polyphenoloxidase (PPO) activity after the treatment was estimated as per the procedure provided by Cano et al. (1997).

Vacuum Treatment

The raw banana slices were immersed in pure water or 10 % NaCl containing water-soluble curcuminoids (0.5 g/100 mL) and subjected to vacuum treatment. The vacuum treatment was performed by placing the sample in a chamber connected to vacuum pump (Model VP115; M/s Jaideep Enterprises, India). The vacuum of 20 kPa (Joshi and Rupasinghe 2010; Hironaka et al. 2011) was applied for 30 min. Then, vacuum was released, and impregnation was continued in the same surrounding solution at atmospheric pressure for 5 h.

Ultrasonication Treatment

The raw banana slices were immersed in pure water or 10 % NaCl containing water-soluble curcuminoids (0.5 g/100 mL) and subjected to ultrasonication treatment in an ultrasonication bath (Model UCB 40; M/s. Spectralab, India). The frequency of ultrasound was 35 kHz, and amplitude was set at 100 %. For 1 cycle, the ultrasound was on for 5 min and off for 25 min. The impregnation was continued in the same surrounding solution for 5 h.

Blanching and Ultrasonication

The banana samples were blanched as per the procedure provided in "Blanching Treatment" section, and ultrasonication

of the blanched samples was performed based on procedure provided in "Ultrasonication Treatment" section.

Vacuum and Ultrasonication

The banana samples were subjected to vacuum treatment as per the procedure provided in "Vacuum Treatment" section, and ultrasonication of the vacuum-treated samples was performed based on procedure provided in "Ultrasonication Treatment" section.

The water loss/gain and solid gain/loss at each interval of time was expressed in grams per 100 g of sample on dry weight basis. All the experiments were carried out in triplicate, and the average value was reported.

Physico-chemical Analysis

Estimation of Curcuminoids

The dried samples containing curcuminoids were extracted using acetone, and the curcuminoid content was determined as per the standard procedure (ASTA 1985; Bellary et al. 2011). The total curcuminoid content was expressed as milligrams per 100 g of sample on dry weight basis. The average curcuminoid flux rate was expressed as per the following equation:

$$\text{Average curcuminoids flux} = \frac{\text{Curcuminoids infused}}{\text{Immersion time}} \quad (1)$$

Texture Analysis

The texture of osmotic dehydrated banana samples was inferred from the maximum force required to compress banana sample to 50 % of its height in a first cycle of texture profile analysis. Uniaxial compression was performed by using a flat-bottomed circular base (100 mm in diameter) at a compression speed of 1.0 m ms^{-1} using a texture-measuring instrument (Model #TAHD; M/s. Stable Microsystems, Survey, UK). The test was performed for five replicates from different experiments, and average values were reported.

The crispness of the dehydrated product was measured in terms of breaking strength, which is the force required for breaking the dehydrated product using three-point bend rig (A/3PB), which is standard attachment. It consists of base with two adjustable supports and one flexure unit. A flexure unit is attached to the load cell. Rollers are provided on both supports and the flexure unit to minimize friction during the test. Measurements were made at a loading speed of 0.83 mm/s with a 50-kg load cell. The experiments were repeated for five times, and average values were reported.

The extent of bending (or curling) was measured using the distortion level in the dehydrated samples by the image analysis using Image J software (Abramoff et al. 2004; Rasband 1997). The distortion level was defined as the distance between the base line and peak height. Wherever the bending or curling was higher, the distortion level was higher. Maximum distortion was measured in pixel by using straight-line measurement and converted into millimetres by using scale factor. The measurement was done in triplicate, and average values were reported.

Colour Analysis

Colour characteristics (L^*, a^* and b^*) of impregnated raw banana slices with curcuminoids as well as

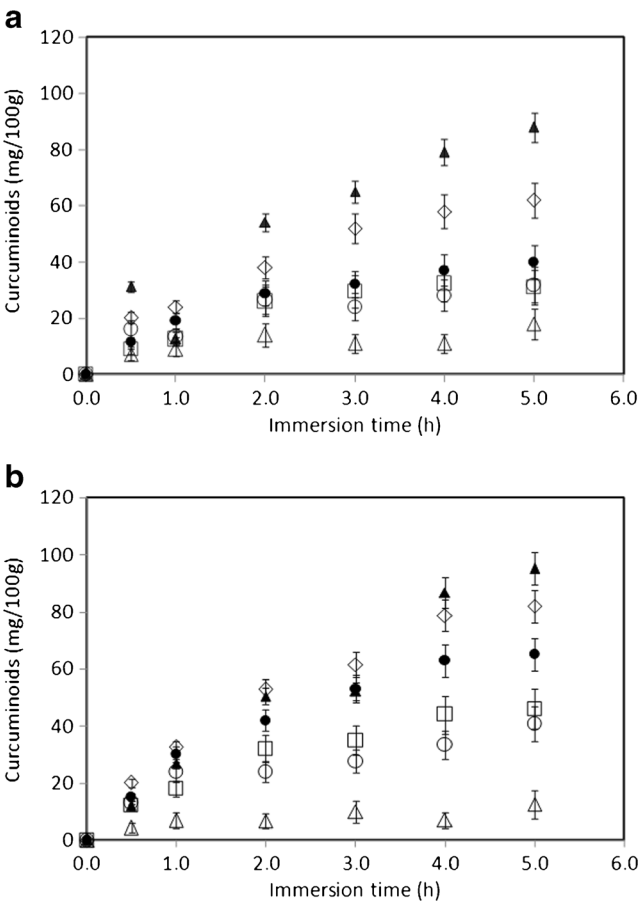

Fig. 1 Variation in curcuminoid content at **(a)** pure water and **(b)** 10 % of salt concentration with surrounding solution concentration with immersion time. *Empty circle* indicates control; *empty triangle* blanching treatment, T_1; *empty square* vacuum treatment, T_2; *empty diamond* ultrasonication treatment, T_3; *filled circle* combined blanching and ultrasonication treatment, T_4; and *filled triangle* combined vacuum and ultrasonication treatment, T_5

dehydrated slices were measured using the Hunter colorimeter (Model D25-9; M/s. Hunterlab, VA, USA). The apparatus was calibrated using a standard white tile. Each measurement represented the average of three readings. L represents the lightness, $+a$ the red direction, $-a$ the green direction, $+b$ the yellow direction, and $-b$ the blue direction (Hunter and Harold 1987). The total colour difference was determined using the following equation (Romano et al. 2008):

$$\Delta E = \sqrt{\left[\left(L^{*}-L_{o}^{*}\right)^{2} + \left(a^{*}-a_{o}^{*}\right)^{2} + \left(b^{*}-b_{o}^{*}\right)^{2}\right]} \quad (2)$$

Examination of Microstructure

The control and treated banana samples were freeze-dried and mounted on aluminium stubs with conductive adhesive followed by coating with gold, employing a sputter coater. The samples were viewed at ×500 magnification to study the structure modification. All examinations were carried out at 15 kV using a scanning electron microscope (Model 435 VP; M/s. Leo Electron Microscopy Ltd., Cambridge, UK).

Calculation of Water/Solid Loss/Gain During Osmotic Treatment

The water gain or water loss (WG or WL) as well as solid gain or solid loss (SG or SL) during osmotic pretreatment for 100 g of product were calculated as per the procedure reported elsewhere (Mastrocola et al. 1998)

$$\text{WG or WL} = [(w \times m_{f}/100) - m_{c}] \quad (3)$$

$$\text{SG or SL} = [(w \times s_{f}/100) - s_{c}] \quad (4)$$

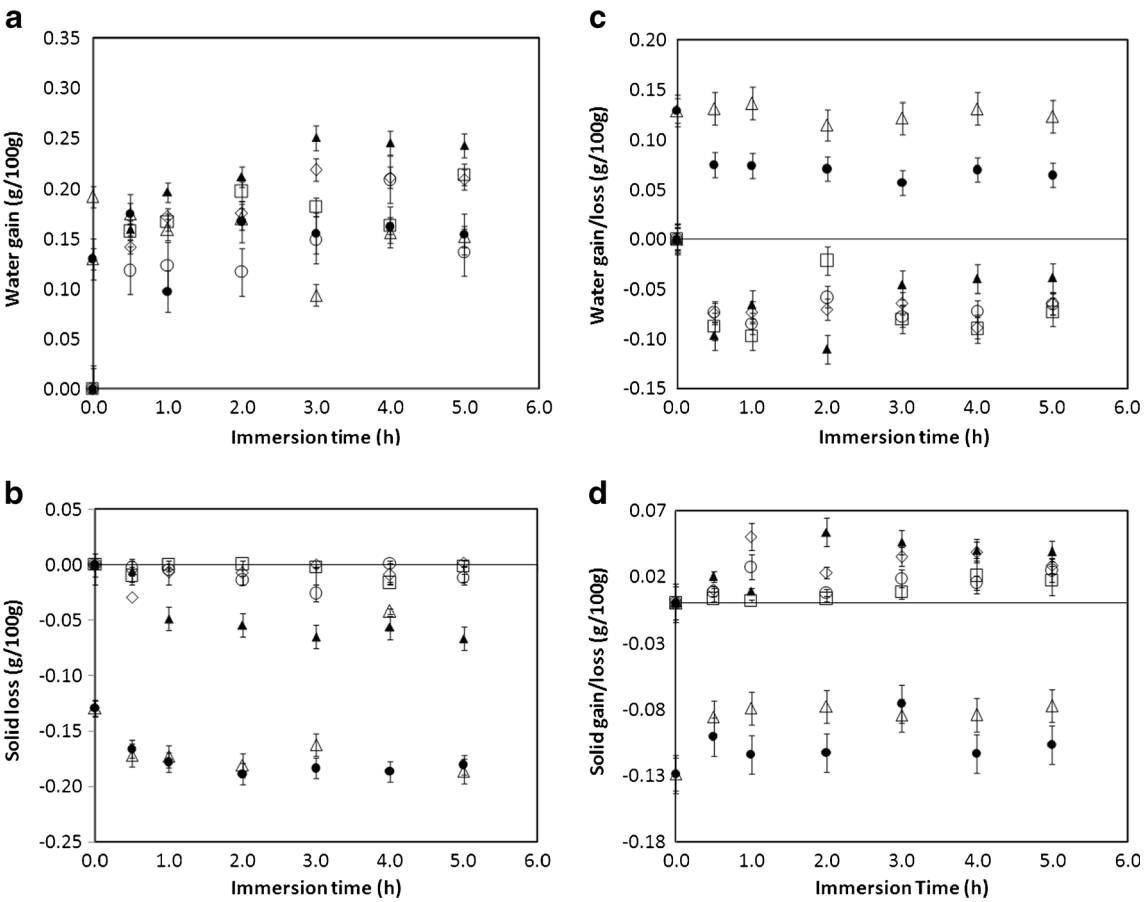

Fig. 2 Variation in water gain (**a**) and solid loss (**b**) at pure water and 10 % of salt concentration with surrounding solution concentration with immersion time. *Empty circle* indicates control; *empty triangle* blanch treatment, T_1; *empty square* vacuum treatment, T_2; *empty diamond* ultrasonication treatment, T_3; *filled circle* combined blanching and ultrasonication treatment, T_4; and *filled triangle* combined vacuum and ultrasonication treatment, T_5

where w is the sample weight before osmotic dehydration; m_f and m_c are the moisture contents after osmotic dehydration and drying, respectively; s_f and s_c are the solid content after osmotic dehydration and drying, respectively.

Drying of Curcuminoid-Infused Banana Slices

The banana slices after pretreatments and osmotic treatment were dried in a hot air dryer. The hot air dryer consisted of a through-flow chamber with a provision to control temperature and air flow velocity. The samples were dried at 55 °C at an air rate of 4.0 m/s (Rozek et al. 2010b).

Statistical Analysis

Statistical analyses were carried out using MSTAT-C software. Data was subjected to analysis of variance (ANOVA) (two factors without replication) followed by Tukey's comparison of means at $p \leq 0.05$, and means were compared using t test between the pretreatments.

Results and Discussion

Effect of Various Treatments on Curcuminoid Infusion, Water Loss/Gain and Solid Gain/Loss

The banana slices were subjected to various pretreatments (blanching treatment, T_1; vacuum treatment, T_2; ultrasonication treatment, T_3; blanching and ultrasonication treatment, T_4; as well as vacuum and ultrasonication treatment, T_5) in a surrounding solution containing pure water or 10 % NaCl and curcuminoids. The variations in curcuminoid infusion as well as water loss/gain and solid gain/loss have been presented in Figs. 1 and 2, respectively.

The immersion of banana slices in surrounding solution (0 %, water) containing curcuminoids resulted in its infusion in banana slices, which continued to increase significantly ($p \leq 0.05$) up to 3 h with immersion time for all the pretreatments (Fig. 1a). At the same time, it also resulted in diffusion of water into a banana sample (due to the higher osmotic pressure inside the banana cells) and diffusion out of banana solids into a surrounding medium (Fig. 2a, b). It has been demonstrated that when food is immersed in water, it results in permeabilization of cells due to the difference in the osmotic pressures between the food and surrounding solution (Rastogi et al. 2000), leading to the impregnation of curcuminoids because of being soluble in water without significantly contributing to osmotic pressure.

T_3 resulted in significantly higher infusion of curcuminoids and higher water loss as compared to control ($p \leq 0.05$, Figs. 1a and 2a) due to increased cell wall permeability (lower resistance) owing to the formation of microscopic channels, which facilitated the transport of water and solute (Carcel et al. 2007; Fernandes et al. 2008; Rastogi 2011). Similar trend was for curcuminoid infusion and water gain observed for T_2. The experimental conditions for vacuum application (vacuum application time, 30 min; relaxation time, 3 h) were chosen based on the data presented with regard to the infusion of curcuminoids (Fig. 3). The curcuminoid infusion was found to increase with an increase in vacuum application time up to 30 min (Fig. 3a) and restoration time up to 180 min (Fig. 3b), and beyond these timings, the infusion did not increase significantly ($p \leq 0.05$). Vacuum impregnation treatment in an external solution is based on the immersion of vegetables into the solution under vacuum for a certain vacuum period and then restoration of atmospheric pressure. The application of vacuum helps in expelling the gas occluded in intercellular voids, which are occupied by osmotic solution when pressure is restored, resulting in an increase of the available mass transfer surface area (Fito 1994; Rastogi and Raghavarao 1996). During the first step, the gas and native liquid are partially expelled, and the pores expand on the basis of mechanical properties of vegetable tissues, whereas, during the second step, the pores are impregnated from the external

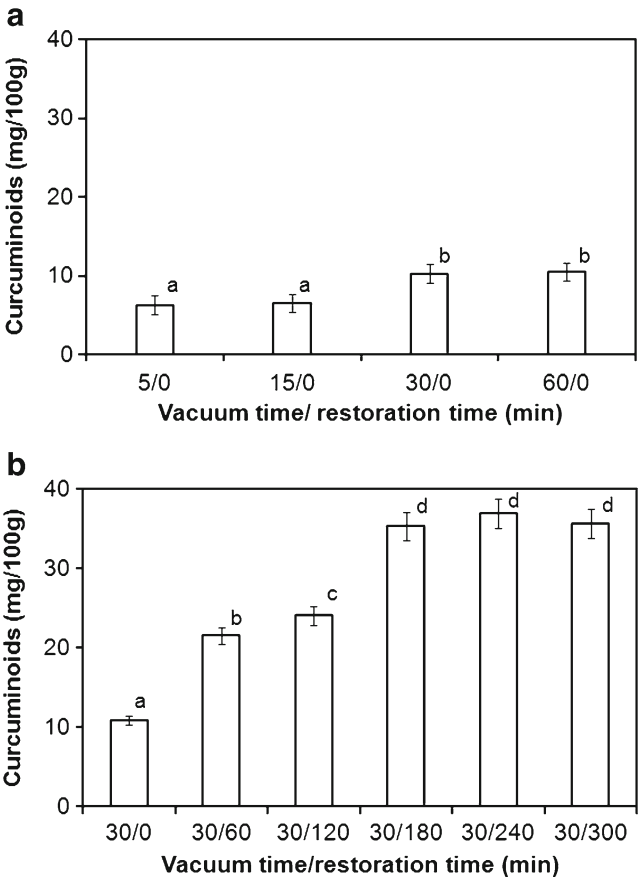

Fig. 3 Variation in curcuminoid infusion with **(a)** vacuum application time and **(b)** restoration time. *Different letters* represent a significant difference at $p \leq 0.05$

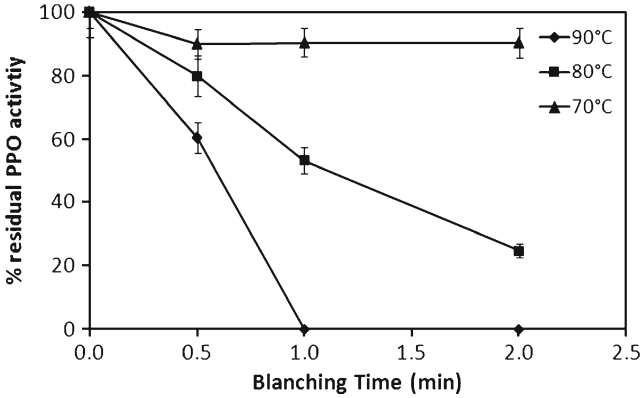

Fig. 4 Effect of blanching time on percent residual activity of polyphenol oxidase (*PPO*) enzyme

liquid on the basis of hydrodynamic mechanisms and relaxation–deformation phenomena (Chiralt and Fito 2003; Schulze et al. 2012; Derossi et al. 2013a, b).

However, solute gain for ultrasonication and vacuum treatments (T_2 and T_3) was not found to be significant as compared to control ($p \leq 0.05$, Fig. 2a, b). The combination of vacuum pretreatment with ultrasonication (T_5) resulted in higher infusion of curcuminoids (85 mg/100 g), significantly higher water gain as well as higher solid loss as compared to T_2 or T_3 individual treatments ($p \leq 0.05$, Fig. 2a, b). Similarly, Comandini et al. (2010) also demonstrated that the combined vacuum and ultrasound treatment resulted in the highest enrichment of green apple aroma in apple sticks.

The blanching conditions were selected based on the inactivation of endogenous PPO present in banana (Fig. 4). High-temperature short-time condition (90 °C, 1 min) was selected for blanching treatment. Moreover, blanching of banana at higher temperature (80–90 °C) was reported to reduce the loss of amylose in the surrounding blanching water (Osundahunsi 2009). T_1 immediately resulted in water gain (0.13/100 g) and loss of solids (0.14/100 g); however, the curcuminoid content was found to be less than that of the control (Fig. 1a). It may be due to the gelatinisation of starch present in banana sample at blanching temperature. It might have served as a barrier to curcuminoid infusion into the sample. Further, the increase in water gain and solid loss was found to increase with immersion time up to 1 h, beyond which no significant changes were observed ($p \leq 0.05$, Fig. 2a, b). Adeva et al. (1968) and Jackson et al. (1996) demonstrated that blanching the banana slices (100 °C, 30 s or 69 °C, 22 min) resulted in enzyme inactivation, which prevented browning leading to enhanced crispness of fried product. The combination of blanching pretreatment with ultrasonication (T_4) resulted in higher infusion of curcuminoids, but water loss and solid gain behaviour did not change significantly.

The increase in the concentration of osmotic solution to 10 % NaCl resulted in an increase in the osmotic pressure of surrounding solution, which led to the reversal in the direction of moisture as well as solid mass transfer (Fig. 2c, d). However, the concentration of curcuminoids significantly ($p \leq 0.05$) increased continuously with an increase in immersion time. The highest infusion of curcuminoids (95 mg/100 g) was found for the combined vacuum and ultrasonication treatment (Fig. 1b, $p \leq 0.05$). There is a threshold osmotic pressure or osmotic solution concentration above which the osmotic removal of water takes place. In this situation, water from the sample was diffused out, and solids

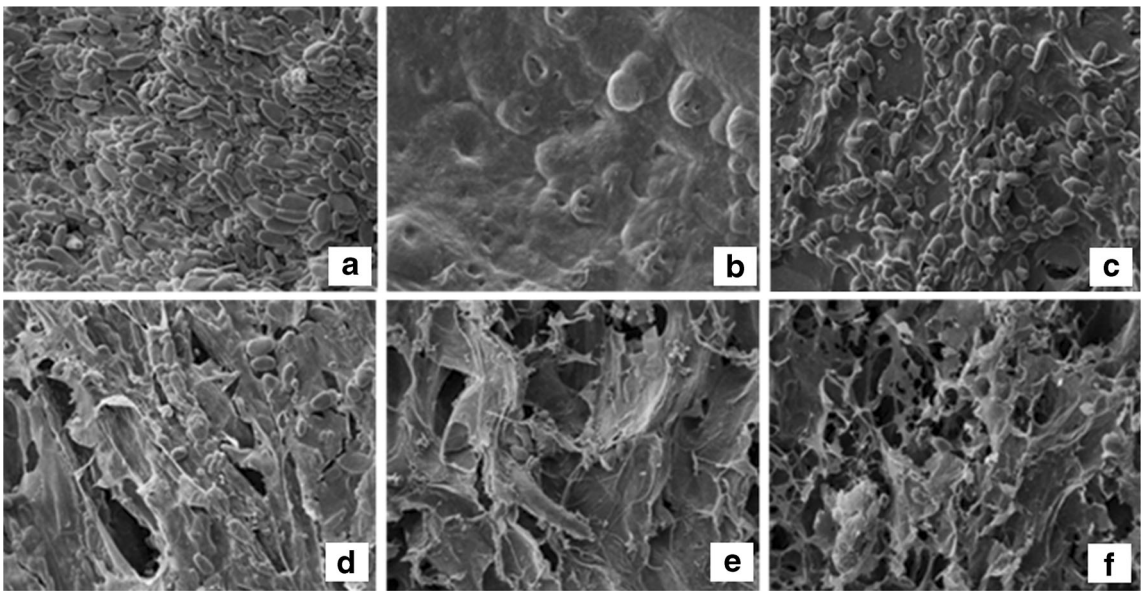

Fig. 5 Effect of different pretreatments on microstructure or raw banana slices: **(a)** control; **(b)** blanching treatment, T_1; **(c)** vacuum treatment, T_2; **(d)** ultrasonication treatment, T_3; **(e)** combined blanching and ultrasonication treatment, T_4; and **(f)** combined vacuum and ultrasonication treatment, T_5 (magnification, ×500)

from surrounding hypertonic NaCl solution were infused into the food matrix. Moreover, the state of cell membrane changes from partial to total permeability, leading to significant changes in tissue architecture (Rastogi et al. 2000, 2002). Lenart and Flink (1984) also reported that NaCl can diffuse inside the cytoplasm and generates concentration gradients at the vacuole level and cytoplasm, allowing transfer of more water from deep inside the cell. Further, Rozek et al. (2008) indicated that NaCl due to its low molecular weight has the significant effect on water loss. Herman-Lara et al. (2013) pointed out that increase in brine concentration resulted in an increase in the solute diffusivities due to greater osmotic pressure.

It is very much obvious from Fig. 1 that T_5 had higher average flux rate (curcuminoids infused/time) as compared to control and other treatments. Moreover, the curcuminoid flux rate was found to decrease with time for all the treatments. When no salt was added in the surrounding solution, the average flux rates for control (C), T_1, T_2, T_3, T_4 as well as T_5 were found to be 2.09, 6.26, 6.26, 7.83, 12.26 and 17.22 mg/100 g/h, respectively. Similarly, when 10 % salt was added in the surrounding solution, the corresponding values of curcuminoid flux rate were 2.31, 8.21, 9.24, 13.09, 16.43 and 18.99 mg/100 g/h, respectively.

Effect of Various Treatments on Microstructure

The microstructures of fresh raw banana sample (C) were compared with the samples subjected to treatments T_1 to T_5. The fresh raw banana slices (control) consisted of long and elongated oval-shaped granules of starch, which were closely clustered but irregularly shaped and embedded densely in a matrix (Fig. 5a). The blanching of banana (T_1) resulted in gelatinisation of starch leading to the hydration and swelling of the starch granules, loss of birefringence and crystalline order as well as uncoiling and dissociation of double helices in the crystalline regions and amylose leaching (Fig. 5b) (Donovan 1979; Evans and Haismann 1982). Probably due to this reason, the extent of infusion of curcuminoids in banana was lower in blanched sample (Fig. 1a, b).

The application of T_3 to the raw banana slices resulted in ruptures of the vapour-filled bubbles due to the formation of cavitation resulting in the formation of microscopic channels in the unlignified cells, which disturbed the pattern of starch granules (Fig. 5d), thus enhancing the impregnation of curcuminoids in raw banana slices (Fig. 1). Similarly, T_4 was found to have a similar effect of rupturing the gelatinised starch (Fig. 5e). Due to this, the infusion of curcuminoids was found to be higher in blanched and ultrasound-treated samples (T_4) as compared to blanched sample (T_1) (Fig. 1).

The vacuum treatment of banana slices though increased the infusion of curcuminoids, but no visual changes were seen in microstructure (T_2) (Fig. 5c). It may probably be due to the removal of the limited level of gas present in banana tissues due to vacuum application because of its structure and composition. Mujica-Paz et al. (2003) has also reported that vacuum application which caused irreversible deformation of cell reduced the free volume available for impregnation in porous foods like banana, mainly, which caused deformation of cells at various vacuum levels. However, significant changes in the cell structure were noticed when vacuum treatment was coupled with ultrasound (T_5) (Fig. 5f) due to the combined effect of vacuum and ultrasonication.

Effect of Treatments on Texture and Colour Difference

The maximum compressive force of banana slices subjected to various treatments (T_1 to T_5) in conjunction with osmotic treatment in surrounding solution containing 10 % NaCl and curcuminoids was significantly lower as compared to that of the control sample ($p \leq 0.05$, Fig. 6a). The lowest compressive force was required for the samples subjected to combined

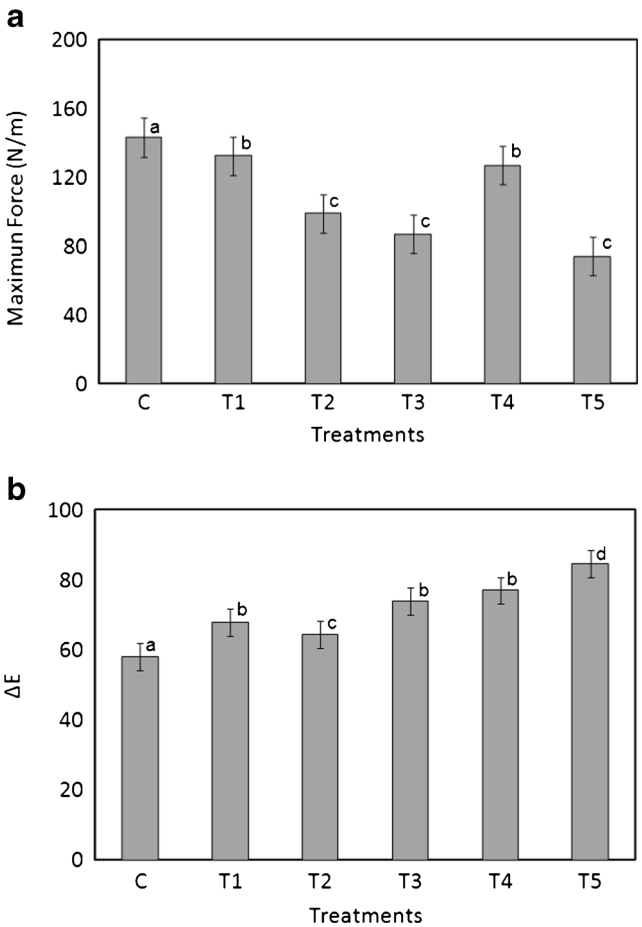

Fig. 6 Effect of treatments on **(a)** texture and **(b)** total colour difference (ΔE) of banana slices at 10 % NaCl osmotic solution concentration. *C* control, T_1 blanch treatment, T_2 vacuum treatment, T_3 ultrasonication treatment, T_4 combined blanching and ultrasonication treatment, T_5 combined vacuum and ultrasonication treatment. *Different letters* represent a significant difference at $p \leq 0.05$

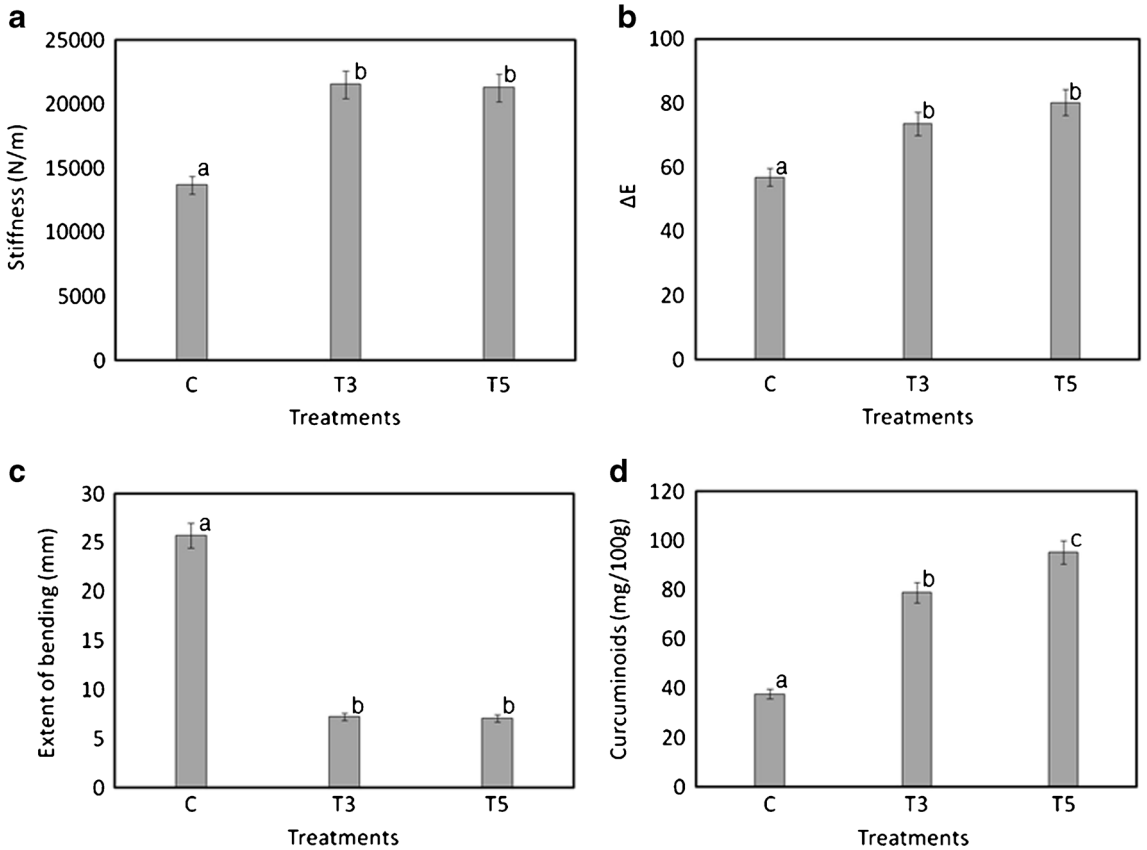

Fig. 7 Effect of treatments on breaking stress (**a**), total colour difference (ΔE) (**b**), extent of bending (**c**) and curcuminoid content (**d**) of banana slices at 10 % NaCl osmotic solution concentration. *Different letters* represent a significant difference at $p \leq 0.05$

vacuum and ultrasonication treatment. These observations corroborated well with the examination of microstructure (Fig. 5), and it can be concluded that higher cell disintegration results in higher infusion of curcuminoids (Fig. 1b). A decrease in the compressive force of treated fruits leading to structural and architectural changes was reported in the case of kiwi, apple and mango (Monsalve-Gonzalez et al. 1993; Robbers et al. 1997; Tedjo et al. 2002).

The major changes were observed in 'b*' values (yellow colour), and L* and a* values did not change significantly ($p \leq 0.05$). Hence, total colour change (ΔE) can be considered as the extent of yellow colour imparted to the banana sample due to curcuminoid infusion. The ΔE of treated samples was found to be highest for the vacuum and sonicated treated (T_5) sample (Fig. 6b).

Effect of Selected Treatments on Quality Characters of Dehydrated Product

The curcuminoid infusion was higher in samples subjected to T_3 and T_5 (Fig. 1b). The quality characteristics of these two samples after finished drying (55 °C, 6–8 h) in hot air oven were compared (Fig. 7). The crispness (as breaking strength), extent of bending (or curling) and total colour difference for T_3 and T_5 treatments were found to be significantly ($p \leq 0.05$) different as compared to control. However, no significant difference was found between T_3 and T_5 treatments (Fig. 7a–c). The curcuminoid retention in the treatment T_5 was found to be significantly higher as compared to control and T_3 treatment ($p \leq 0.05$, Fig. 7d). The highest infusion of curcuminoids for T_5 treatment resulted in significantly ($p \leq 0.05$) higher retention of curcuminoids in the dehydrated products. It may be due to adequate thermal stability of curcuminoids (Zebib et al. 2010). However, the infusion of curcuminoids, besides providing the bioactive properties, resulted in a light yellow-coloured banana chips, which in fact masked the colour development due to non-enzymatic browning taking place during drying operation.

Conclusion

The treatments such as blanching, ultrasound, vacuum and their combinations were found to have a significant effect on the impregnation of curcuminoids and physico-chemical properties of raw banana. The samples

subjected to combined vacuum and ultrasonication treatment were found to result in highest infusion of curcuminoids and lowest compressive force due to changes in the microstructure of the foods. Further, the dehydration of such product also resulted in highest retention of curcuminoids compared to the individual treatments. Thus, the role of pretreatments in conjunction with osmotic treatment for the infusion of bioactive compounds could be justified as a novel process for the development of functional foods without significantly altering the natural food matrix.

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